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ABSTRACT

We have constructed and tested a longitudinal Pockels cell with a clear aperture of 26x26 cm. Transparent plasma electrodes formed in a low pressure glow discharge were used to apply a uniform electric field to a 1 cm thick KDP crystal. Optical switching times of 50 nsec were achieved with a bare KDP crystal. Significant improvement in switching time resulted from using a glass plate-KDP crystal sandwich.

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Large aperture optical switches are potentially of great importance for the realization of the next generation of high energy lasers for inertial confinement fusion (ICF).[1] Large aperture switches may be used for the isolation of amplifier stages in master oscillator-power amplifier chains, for injection and extraction from regenerative amplifier cavities, and for isolation from target retroreflections. No conventional optical switch technology is scalable to the large apertures ($1 \sim 5$ meters) conceived for next generation ICF laser architectures.

We proposed a new approach to the problem of designing large area electro-optical switches and recently tested it on small scale devices.[2,3,4] This approach involves the utilization of ionized gas as large area conducting electrodes for longitudinal electro-optical switches. In this letter we report the successful scale up of this concept to much larger apertures. Using plasma electrodes, we built a Pockels cell with an open aperture of 26x26 cm using a Z-cut KDP crystal of 27x27x1.1cm dimensions. At this size the device is the largest high performance optical switch ever built and can now be considered for use in new large laser system architectures.

Figure 1 shows the photograph of the Pockels cell. The cell body is machined from lucite and consists of two separate discharge chambers separated by the center section which holds the electro-optical crystal. In this cell the crystal can be mounted "bare", i.e. with plasma directly in contact with its surfaces, or in a "sandwich" geometry with the crystal located between two glass plates.[3] The "bare" crystal Pockels cell has the advantage of mechanical simplicity and smallest number of optical surfaces. However, it does require development of high quality anti-reflection coatings for KDP. Also, the bare crystal has high capacitance and relatively low half-wave voltage. This results in significantly slower turn-on times compared to the "sandwich" configuration.[3] In our 26x26 cm Pockels cell we tested both the "bare" and the "sandwich" configurations with the results confirming our expectations.

Figure 2 shows the four electrode geometry for creating the plasma electrodes and the electrical circuit for applying the switching voltage. Pairs of electrodes on the same side of the crystal are used to establish plasma in both chambers, with minimum voltage applied across the crystal. Following pre-ionization, the main switching pulse is applied to a pair of electrodes on the opposing sides of the crystal. The voltage pulse charges-up the crystal faces using the plasma as the conducting electrode. A 1μsec duration pre-ionization pulse of nominally 30 kV breaks down the gas to form the plasma, and after a 200 nsec delay, triggers the main switching pulser. A 50 nsec transmission line at 25Ω impedance (two RG 217 cables) couples the main pulser to the Pockels cell. The driving line is terminated at the cell with a 25Ω load for the "sandwich" configuration and with a 10Ω load for the "bare" crystal Pockels cell. The ballast resistance for each pre-ionization electrode was 250Ω. Prior to operation, the discharge chambers are evacuated and filled with helium gas. Typical operating pressures are in the range of 5-10 torr.

The Pockels cell was routinely operated at approximately one pulse per second for many hours during the course of experiments without any observable degradation of performance. An occasional pumping-out and refill of the cell with He was required, however, due to the slow build-up of impurities in the gas due to outgassing of the lucite. Exposure to the plasma discharge caused no observable deterioration of the KDP crystal surfaces.

The optical performance of the Pockels cell was monitored using a single-mode CW argon-ion laser of nominally 1 watt output at 514.5 nm to probe discrete points on the aperture. This is illustrated in Fig. 3. A vacuum photodiode with an S-20 cathode and subnanosecond response time was used as a detector. Crossed polarizers were placed at the laser and at the detector. The argon-ion laser was aligned to propagate along the Z-axis of the crystal by monitoring the isogyre pattern at each probed point. Figure 4a shows the voltage pulse, measured by a calibrated high-voltage probe, applied to the electrodes of the Pockels cell and the optical transmission at points A and B on the bare crystal. Point A was mid-way up the crystal on the side nearest the main switching electrodes, whereas point B was on the far side nearest the pre-ionization electrodes. At the voltage corresponding to a half-wave retardation at

514.5 nm the switching time of the Pockels cell is $\sim$ 100 ns. In this operating regime, the Pockels cell resembles a resistive transmission line and the switching time is determined by the diffusion of charge across the aperture. Figure 4b shows the results observed at twice the voltage, which corresponds to a half-wave retardation for 1μ light, which is of interest for solid state neodymium lasers. Here, the optical data is harder to interpret since the phase retardation goes through a full wave at 514.5 nm. However, the analysis shows the switching time to be a factor of two faster. This is expected since the ionization level is higher due to electron avalanching at the higher applied voltage. The total pre-ionizing current in these experiments was measured to be $\sim$ 100 amperes. Further increase in the pre-ionizing current as well as increase of the crystal thickness, which reduces the capacitance, will result in even faster switching times for the "bare" crystal configuration.

The "sandwich" geometry was tested with glass plates of approximately 6mm thickness mounted on each side of the KDP crystal. A 1mm gap between each plate and the KDP crystal was filled with an index matching fluid. Koolase, which is an index-matching fluid for harmonic generation crystals was used here.[5] After a few days we observed a chemical reaction of the Koolase with the lucite walls of the Pockels cell, and even though this did not effect our measurements, we do not recommend this index-matcning fluid for future work. It is also important to note here that the pressure above the index-matching liquid must be kept nearly the same as that in the discharge chamber. If the index-matching liquid is at higher pressure compared to the chamber, the glass plates will be under stress, thus reducing the optical figure of the Pockels cell, and might break if sufficient pressure difference occurs.

The results obtained with this "sandwich" are shown in Fig. 4c. As expected, the half-wave voltage increased, and the switching time became significantly faster. The turn-on time is limited by the high voltage pulser rise-time, which for the 25Ω load used with the "sandwich" was $\sim$ 20 ns. A switching speed comparable to the electro-magnetic propagation time across the crystal ($\sim$ 5 nsec) should be obtainable by improving the high voltage driver.

The field uniformity across the aperture was monitored by firing the pulser at 1.5 times the half-wave voltage and monitoring the optical transmission at a large number of points. The results show that after a charge-up time of $\sim$ 30 ns, all points on the aperture were charged to the same voltage within 10%. This is the size of our experimental error. A diagnostic technique is presently being developed to "freeze-frame" photograph the entire aperture during the turn-on of the optical transmission.

In conclusion, we have demonstrated that the plasma electrode concept is scalable to the large apertures which are of interest for new fusion lasers. There is no reason why the aperture can not be further increased by either growing bigger crystals, or by segmentation. The switching times of our Pockels cell are fast enough for most fusion laser applications and further engineering work should result in even faster large area switches based on this concept.

The authors acknowledge the indispensible contributions of Robert Pasha and Gary Ullery in constructing and testing the large aperture Pockels cell, and the work of the Nova engineering staff, particularly Fritz Frick, Mike Vergino, Don Hughes, and Tom Marchi in laying-out the engineering design and procuring components. We also thank Jeff Williams for useful discussions and John Murray, Howard Lowdermilk and John Emmett for encouraging this work.

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4. M. A. Henesian, J. Goldhar, and R. A. Haas, "Electro-optic Harmonic Conversion Switch for Large Aperture Multi-pass Laser Systems", to be published in Optics Letters, August 1984.
5. "Monolithic Cell for Frequency Conversion", Section 3A, LLE Review, Quarterly Report October-December 1982, Laboratory for Laser Energetics, Univ. of Rochester, Rochester, New York.

Figure Captions

1. Photograph of 26x26 cm aperture Pockels cell mounted on large tilt-rotation table.
2. Electrical circuit for driving four-electrode geometry plasma electrode Pockels cell.
3. Optical layout for testing Pockels cell switching performance at points across the aperture.
4. Applied voltage (kV) and optical transmission (%) vs. time (nsec) for the 26x26 cm Pockels cell.
   (a) Bare crystal cell at half-wave voltage,
   (b) Bare crystal cell at full-wave voltage,
   (c) Sandwich geometry cell at half-wave voltage.

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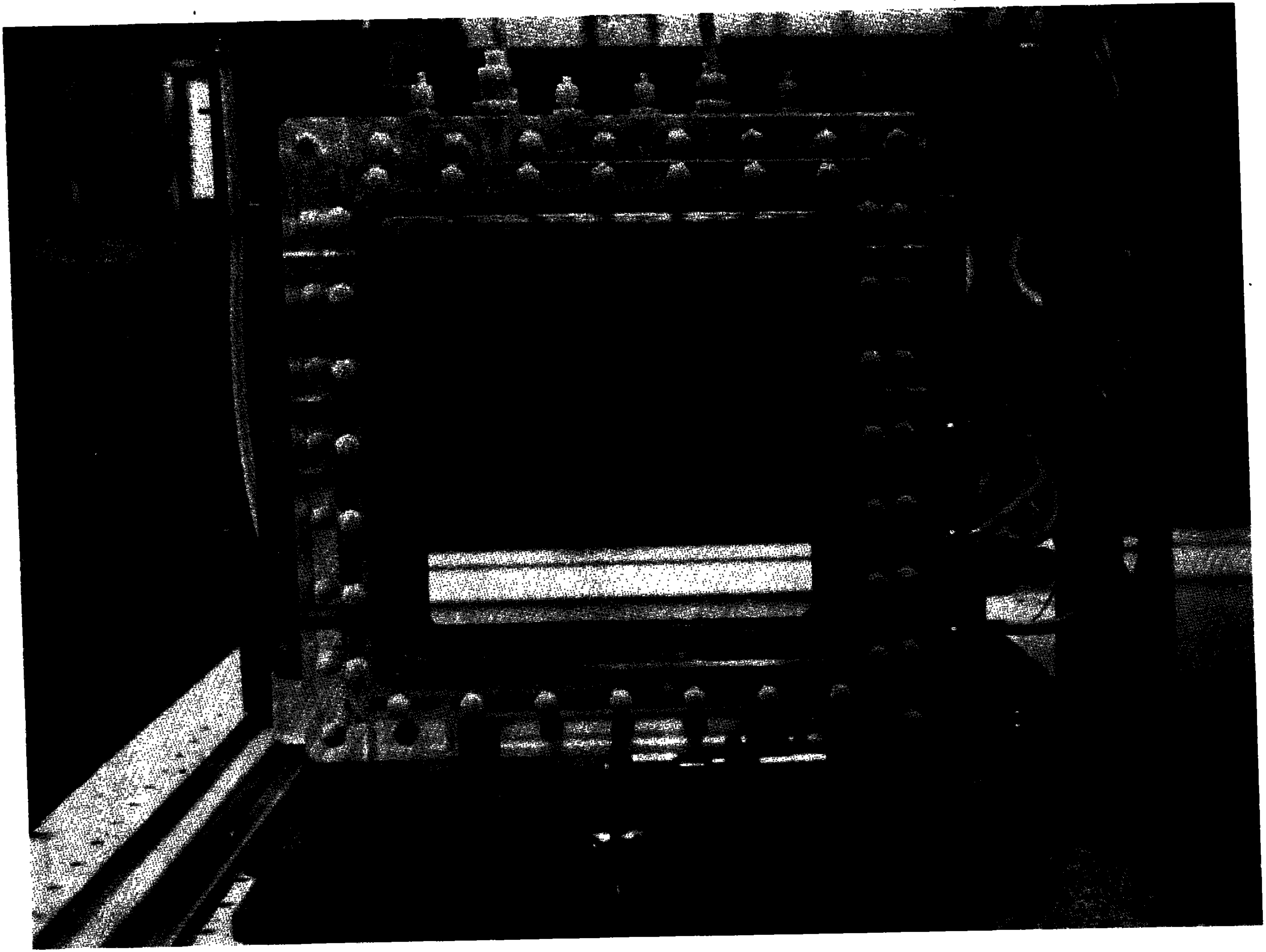


Figure 1

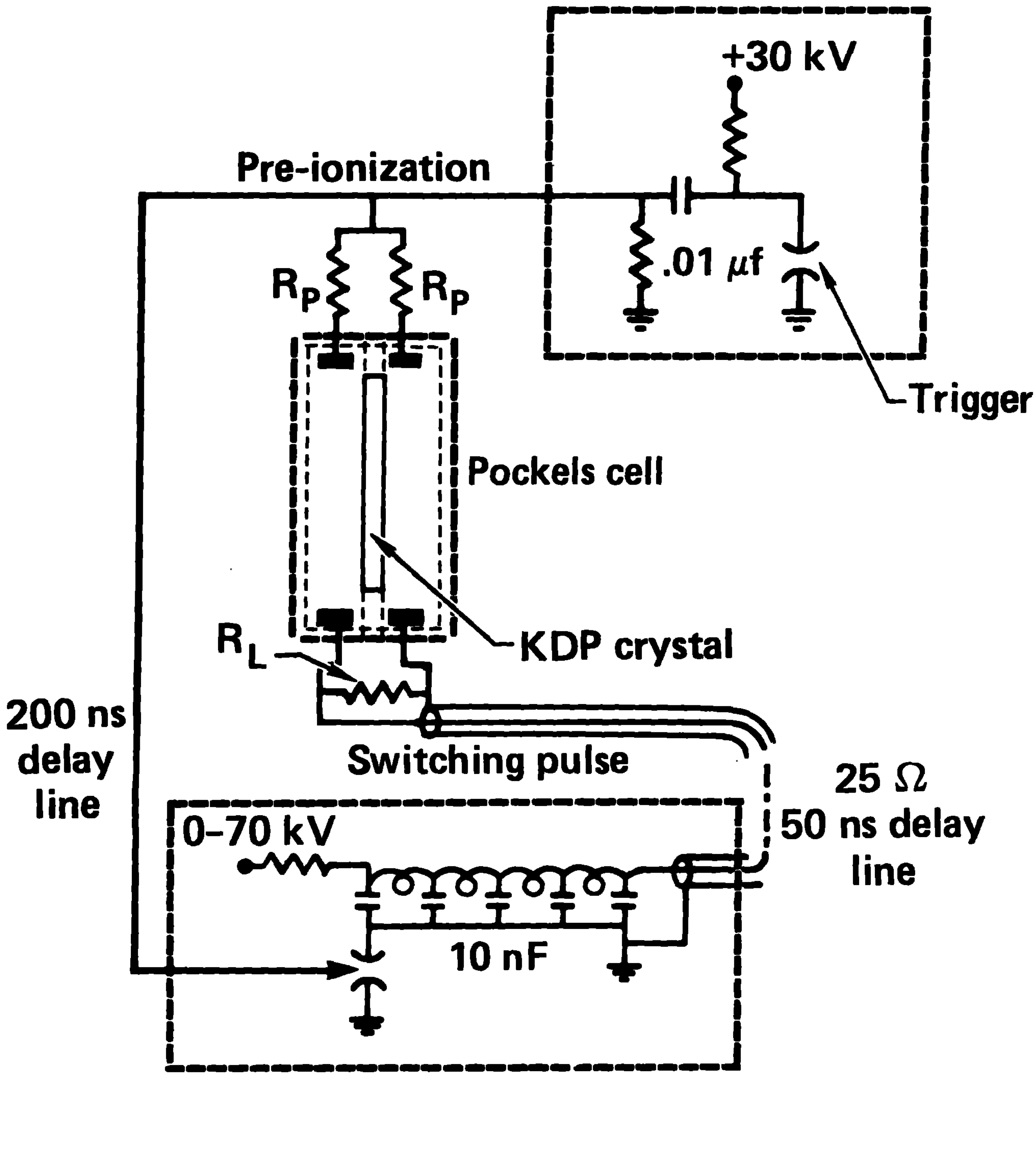

+30 kV
Pre-ionization
.01 μf
R_P
R_P
Trigger
Pockels cell
R_L
KDP crystal
200 ns delay line
Switching pulse
25 Ω 50 ns delay line
0–70 kV
10 nF

Figure 2

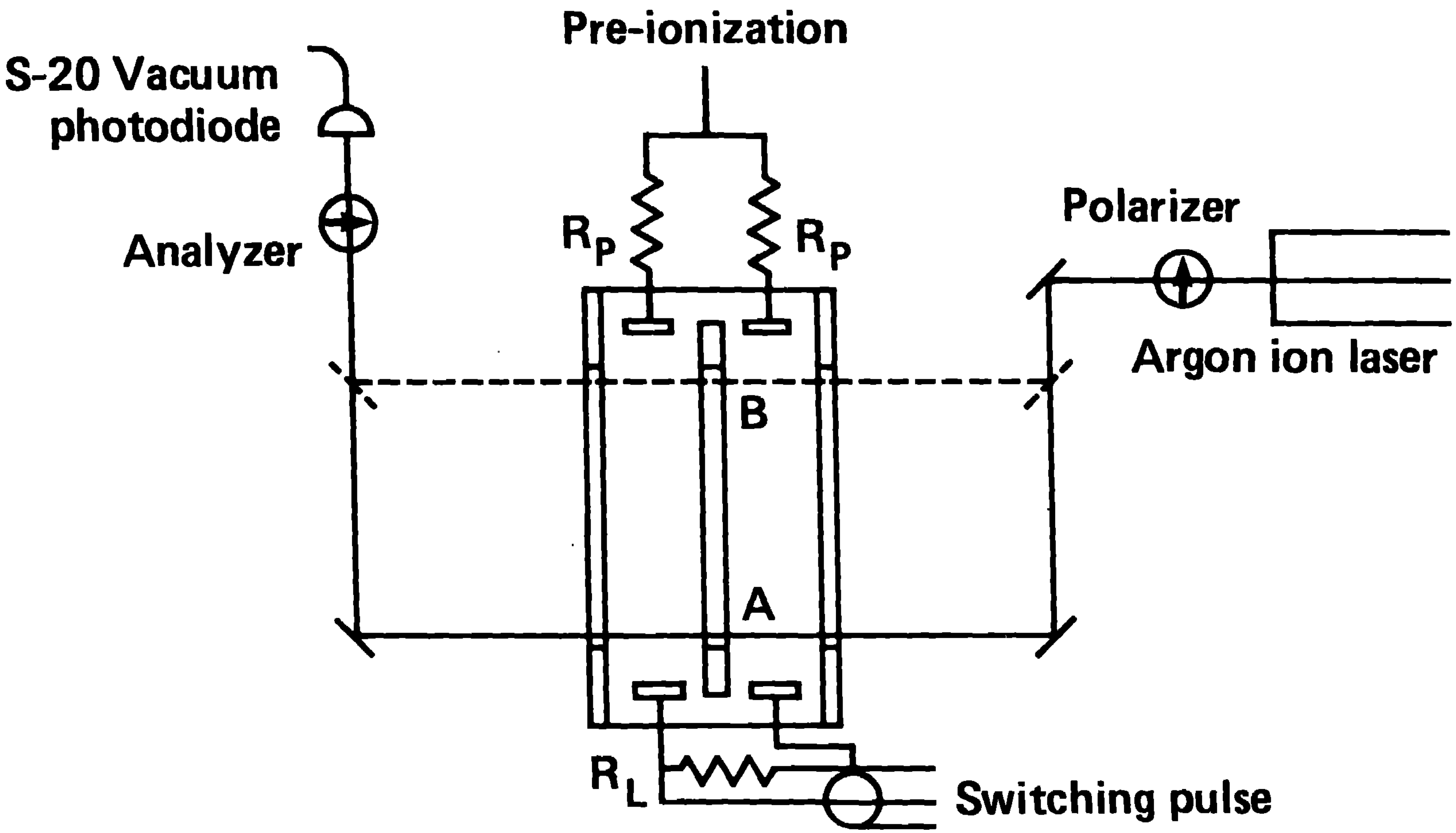

Pre-ionization
S-20 Vacuum photodiode
Analyzer
R_P
R_P
Polarizer
Argon ion laser
B
A
R_L
Switching pulse

Figure 3

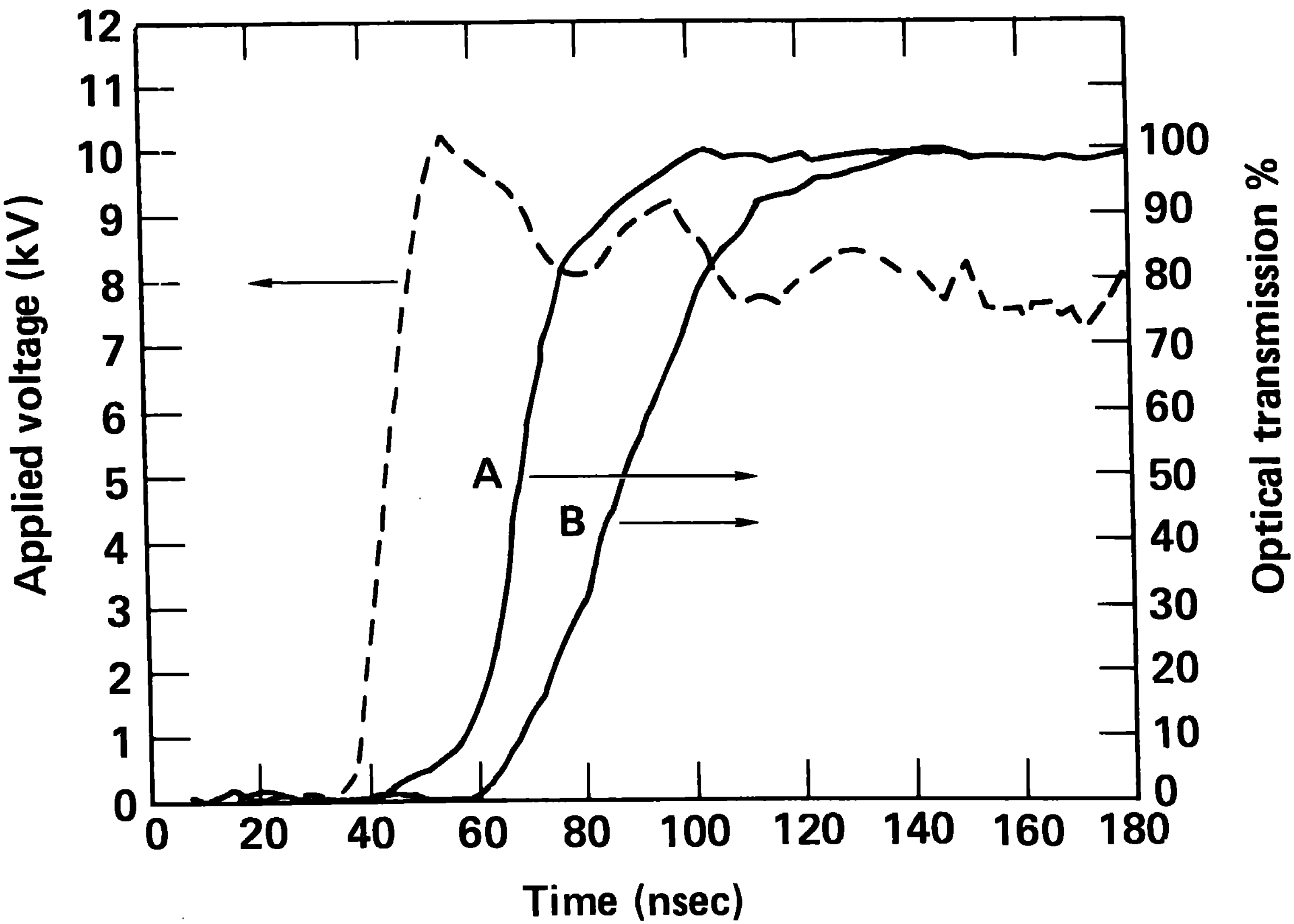
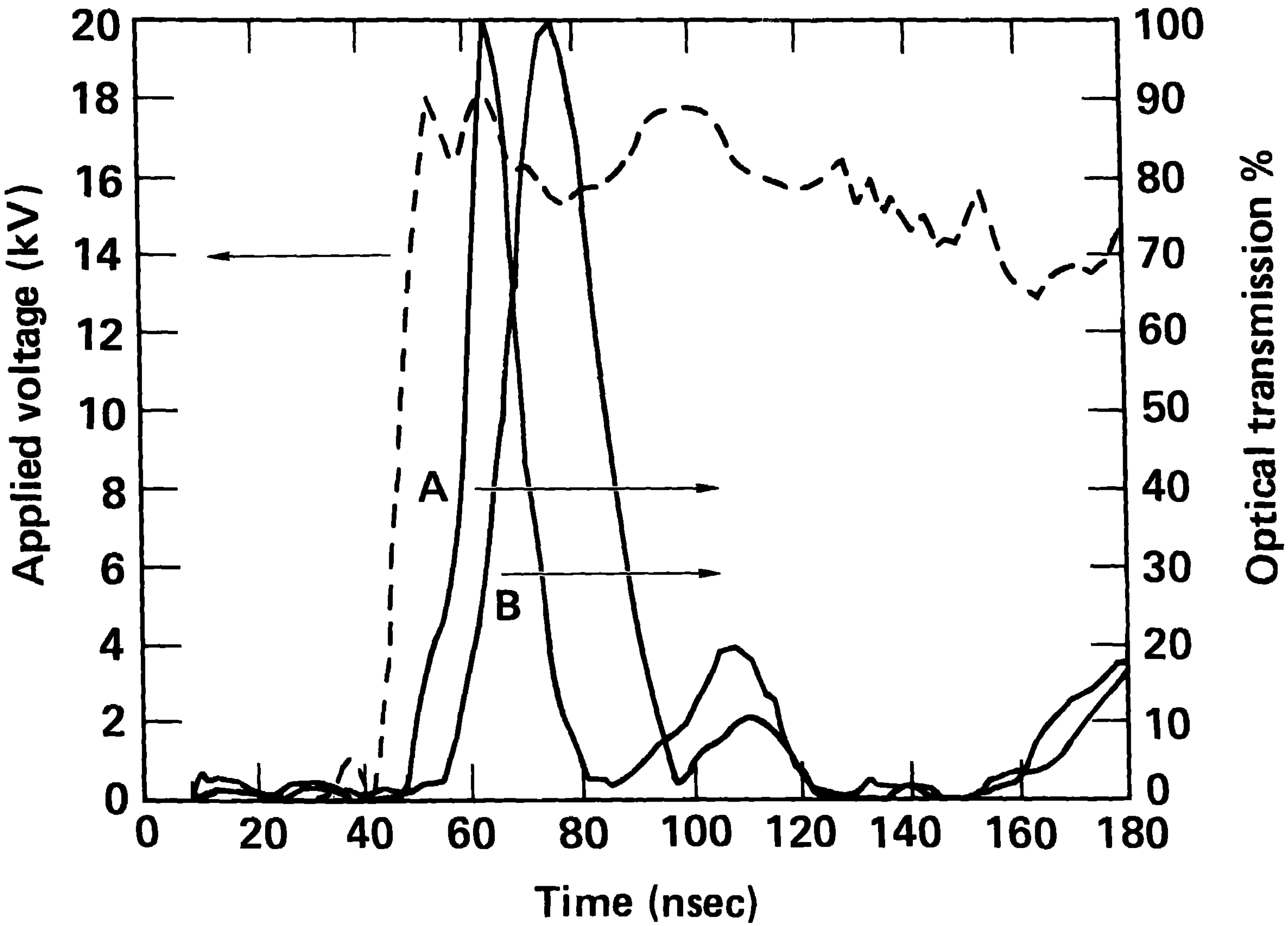
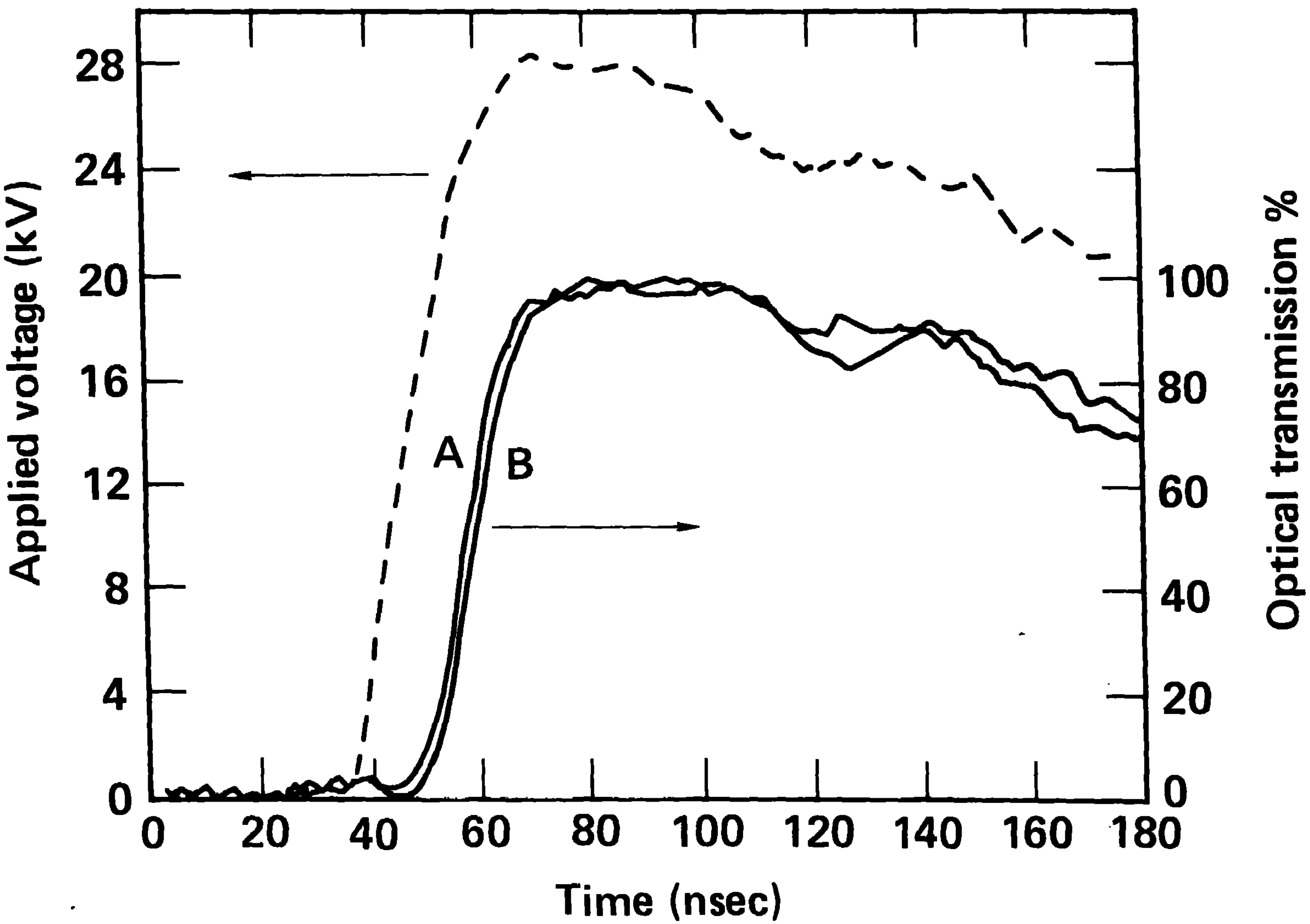

Applied voltage (kV)
12
11
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
180
Time (nsec)
Optical transmission %
100
90
80
70
60
50
40
30
20
10
0
A
B

Figure 4a



Applied voltage (kV)
Optical transmission %
Time (nsec)
A
B
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180

Figure 4b



Applied voltage (kV)
28
24
20
16
12
8
4
0
A
B
Optical transmission %
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
Time (nsec)

Figure 4c